REPORT

Zone of Influence Study

Municipal Class EA for the Proposed Coleraine Drive Grade Separation, South of Old Ellwood Drive, Town of Caledon

Submitted to:

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Distribution List

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Executive Summary

Golder Associates Ltd. (Golder) was retained by CIMA+ to carry out a Vibration Assessment in support of the Coleraine Road Grade Separation Environmental Assessment (EA) Study, undertaken by the Region of Peel. The assessment reviewed two design options (Road Over Rail and Road Under Rail) and included the analysis of the Zone of Influence (ZOI) impacted by ground vibrations produced during anticipated construction operations and their potential impact on neighbouring residential structures.

Pile Drivers (impact and/or vibratory) and Vibratory Rollers will likely be used during construction and being machinery of higher vibration levels, these were used as the example construction equipment for the analysis. As there are currently no Town or Regional vibration guideline limits, the City of Toronto Vibration Control By-Law was used as the guideline limits for this analysis. This by-law is typically used as the reference in the Greater Toronto Area. Thus, a ZOI was established inside which construction vibrations exceeding 5.0 mm/s may occur.

The analysis identified ZOIs for both Road Over Rail and Road Under Rail options and are detailed in Figure 4A and Figure 4B. As an initial screening, a conservative maximum limit was applied to the vibration analysis results (limit of 8 mm/s for all frequencies) to identify key locations. For the Road Over Rail option, two receptors (R1 and R13) showed vibration estimates of 9.14 mm/s. For the Road Under Rail option, two receptors (R1 and R13) showed vibration estimates of 8.24 mm/s. Upon further review, the location of the receptors are at distances such that the frequencies experienced are anticipated to be above 4 Hz. The maximum frequency-based vibration limits for frequencies of >4-10 and >10 Hz are 15 and 25 mm/s, respectively. Thus, the anticipated vibrations will be below guideline limits.

The ZOI for each option extends close to adjacent residences. Where road construction operations (using pile drivers (impact and/or vibratory) and vibratory rollers) occur within 70-160 m of residences, the induced ground vibrations are likely to be perceived and could be an annoyance. Although vibration monitoring is typically only required within the ZOI during construction periods, continuous vibration monitoring tends to provide data which allows for ongoing feedback to the Project Team and to expedite complaint resolution.

It is recommended that:

- Preconstruction condition surveys should be carried out on adjacent residences within the ZOIs. These properties are detailed in Figure 4A and Figure 4B, which are predominantly the first row of homes either backing or siding Coleraine Drive; and
- Vibration monitoring be conducted for the duration of the construction activities.

The estimated number of preconstruction surveys for the Road Over Rail scenario would be 15 homes and for the Road Under Rail scenario it would be 11 homes.

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APPENDIX A
Vibration Terminology

1.0 INTRODUCTION

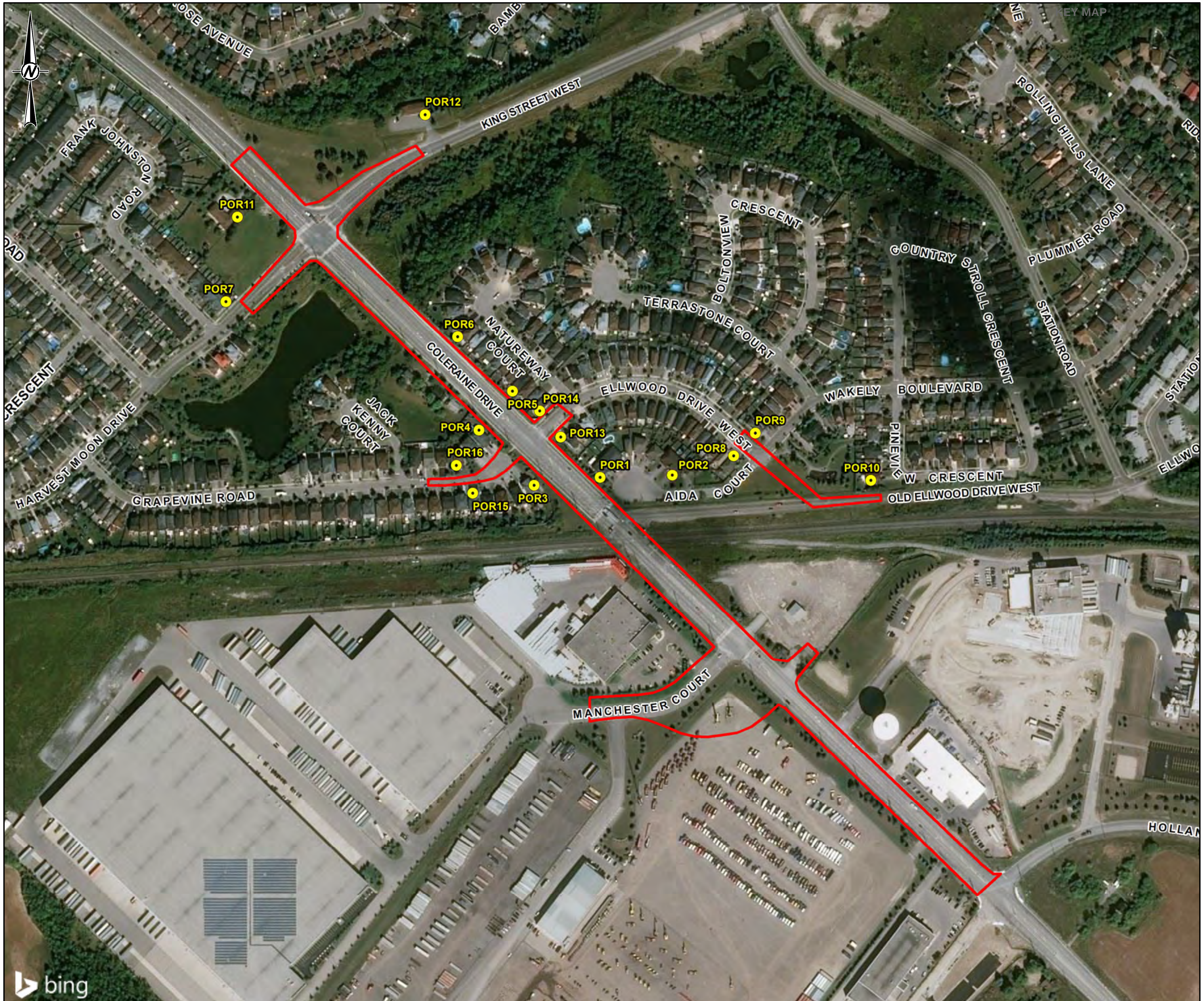
Golder Associates Ltd. (Golder) was retained by CIMA+ to carry out a Vibration Assessment in support of the Coleraine Road Grade Separation Environmental Assessment (EA) Study, undertaken by the Region of Peel. The assessment reviewed two design options (Road Over Rail and Road Under Rail) and included the analysis of the Zone of Influence (ZOI) impacted by ground vibrations produced during anticipated construction operations and their potential impact on neighbouring residential structures. The estimated peak ground vibration levels likely to be generated during these phases of construction will be related to proposed guideline limit and to recognized, published and/or accepted damage criteria.

CIMA+ and the Regional Municipality of Peel (the Region) is considering the widening of the approximately 1.0 km long section of Coleraine Drive located between Harvest Moon Drive/King street West and holland Drive in the Town of Caledon, Ontario. The CP Rail traverses Coleraine Drive south of Old Ellwood Drive, and a tributary of the Humber River crosses Coleraine Drive near the northern limit of the project. In general, residential developments are located to the north of the of CP Rail line while industrial/commercial developments are located to the south. Consideration given to widening the 1.0 km long section for Coleraine Drive; adding one thru lane in each direction and constructing a grade separation structure at the intersection with the CP Rail. The decision of the grade separation structure is not confirmed at this time and both Road Over Rail (Overpass), a structure carrying a road over a railway; and Road Under Rail (Underpass), a structure carrying a railway over a road, are being considered.

This ZOI study considers the potential effects of the vibration levels of the two scenarios for the reconstruction activities on off-site sensitive receptors. Figure 1 illustrates the following:

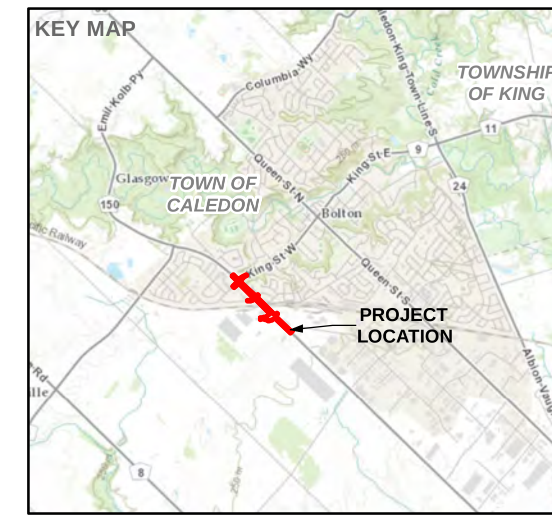
- Study Area (shown in red);
- Adjacent existing residential lots and structures; and
- Sixteen representative sensitive receptors.

It is Golder's understanding based on CIMA+ information the three dwellings in the lot west of R4 on Coleraine Drive will not be present during the construction. As a number of technical terms are used in this technical memorandum, a description of these terms is provided in Appendix A.



LEGEND

- Point of Reception
- Study Area



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3. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83 COORDINATE SYSTEM:UTM ZONE 17N

CLIENT
CIMA+ AND REGIONAL MUNICIPALITY OF PEEL

PROJECT
ZOI, PROPOSED COLERAINE DRIVE GRADE SEPARATION SOUTH OF OLD ELLWOOD DRIVE, TOWN OF CALEDON

TITLE
SITE LOCATION PLAN

CONSULTANT

GOLDER

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2.0 APPLICABLE GROUND VIBRATION LIMIT

The intensity of ground vibration, an elastic effect measured in units of peak particle velocity (PPV), is defined as the speed of excitation of particles within the ground resulting from vibratory motion. Golder is unaware of a ground vibration limit for the proposed project area. Thus, Golder has used the limit outlined in the City of Toronto Vibration Control By-Law, 514-2008, as contained within Chapter 363, subsection 363-3.6 of the Toronto Municipal Code, Building Construction and Demolition (Vibration Control By-Law). This By-Law is typically used as the reference in the GTA area. The limits outlined within Toronto's Vibration Control By-Law are appropriate for the work being carried out and are often used where vibration limits are not in place for projects carried out in the area. Based on the Peel Policy Directive (2013) and based on the Toronto Vibration Control By-Law and its description of the ZOI, a number of recommendations have been made for this study:

- A "Zone of Influence" should be established, which is the area inside of which construction vibrations exceeding 5.0 mm/s may occur.
- Where buildings or structures are identified inside the Zone of Influence, various consultation, inspection and communications protocols and processes are recommended including a vibration monitoring program and pre-construction condition inspections.

Where vibration monitoring is recommended, it should be carried-out continuously at the closest structure to the construction operation. The vibration monitoring is designed to measure vibration levels for maintaining compliance with the maximum frequency-based limits identified in Table 1 below.

Table 1: Prohibited Vibration Limits

Frequency of Vibration (Hz)	Peak Particle Velocity of Vibration (mm/s)
< 4	8
4 – 10	15
> 10	25

Figure 2 illustrates the vibration limits as they relate to frequency.

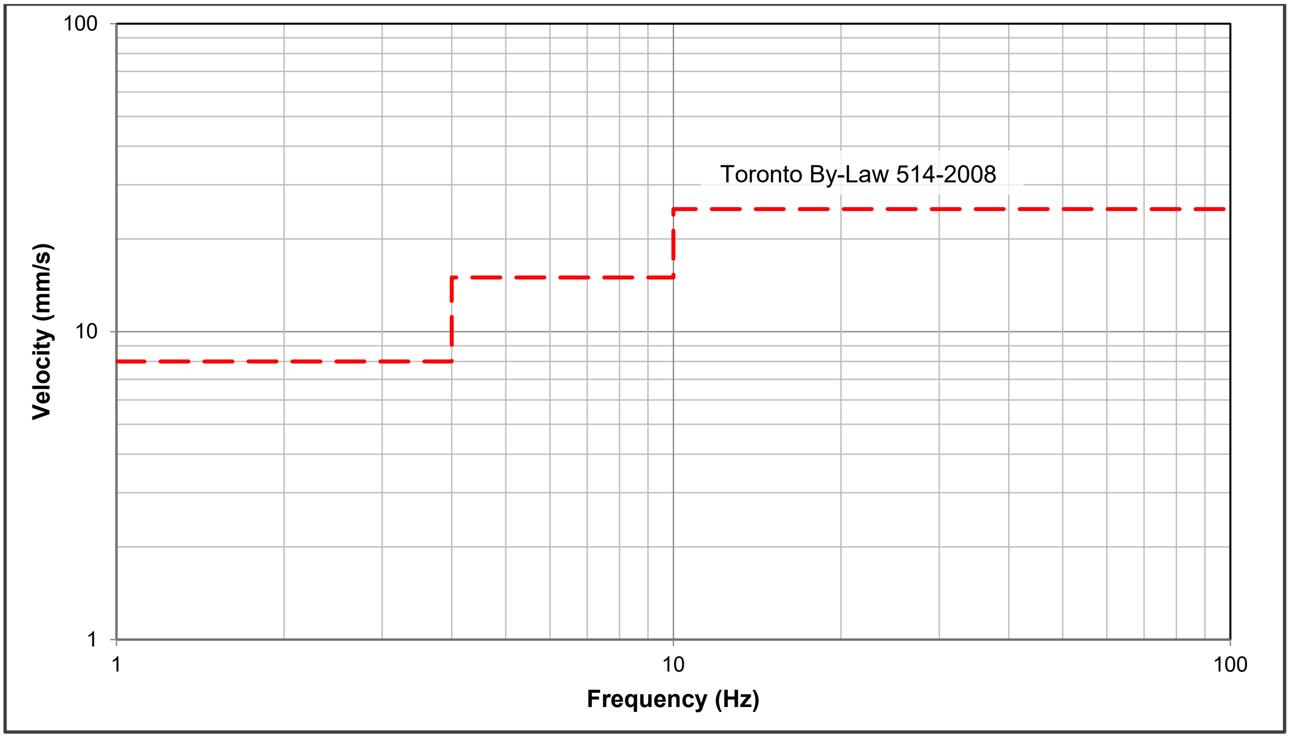


Figure 2: City of Toronto Construction Vibrations By-Law 514-2008

During the development of the predictive vibration model, the conservative limit of 8 mm/s across all frequencies was used in assessing the potential impacts.

The existing ground vibration conditions at the nearby sensitive receptors are expected to be dominated by low level activities, such as vehicular traffic.

Continuous, steady-state vibrations (e.g., from a vibratory compactor) are considered slightly perceptible at a level of approximately 0.3 mm/s (CALTRANS, 2013). Transient vibrations (e.g., from an impact pile driver) are considered barely perceptible at a level of approximately 0.9 mm/s (CALTRANS, 2013).

3.0 GROUND VIBRATION PREDICTION MODEL

The intensity of the vibration produced by each source depends on the input energy, its frequency, the transmission medium, and distance of travel. Sources of construction vibrations generate waves that transmit vibrations through soil medium. The waves travel outward from the construction source and attenuate as a result of geometrical spreading and material damping.

Vibration energy from construction operations can emanate from a variety of sources including:

- Impulsive (breakers, dynamic compaction, impact pile driving);
- Vibrating (vibratory compaction roller, vibratory pile driving);
- Rotating (trencher, drilling/auguring equipment); and
- Rolling (heavy vehicles) type equipment.

CIMA+ provided the following preliminary equipment list for both the excavation and grading, and the asphalt paving scenarios with approximate weights that will be used for the reconstruction of the road for both the overpass and underpass scenario:

- The Excavation and Grading Scenario:
  - Excavators (25-50 Tonnes)
  - Vibratory Rollers (7.5-15.5 Tonnes)
  - Crawler Dozer (7-13 Tonnes)
  - Trucks (Dump trucks and Trailer Trucks)
  - Asphalt Pavers (19-21.5 Tonnes)
  - Asphalt Material Transfer Vehicle (Shuttlebuggy) (34 Tonnes)
  - Asphalt Pavement Profiler (Milling Machine) (23.5-51 Tonnes)

However, the two scenarios for the road construction overpass and underpass it has been assumed the boundaries the equipment would be working within would differ between both scenarios. Since the overpass would be a bridge, we have assumed there would be more pillars, abutments and retaining walls which would require a larger lateral extent along Coleraine Drive for the caisson drill and drill piling to work within. On the other hand, the underpass would require the vibratory pile driver and/or caisson drill to be operated at roughly the same lateral distances along Coleraine Drive as the overpass, but the impact pile driver would be focused closer to the entrance and exit of the underpass.

Information provided to Golder indicates that piles will need to be driven for the project. It is understood that both vibratory and impact pile drivers would be required for the project. Since the specific impact hammer is not currently known, a 60,000 J (44,254 ft-lb) impact hammer has been conservatively assumed for the impact piling. Should a specific hammer become known, the following PPV attenuation model can be revised.

3.1 Empirical Vibration Relationships

A summary of basic empirical relationships for predicting vibration levels from construction equipment, which were developed by earlier researchers, was presented by CALTRANS (2013). The vibration attenuation model for the assumed construction equipment is given by the following:

$$\mathbf{PPV}_{equip} = PPV_{ref}\left(\frac{25}{D}\right)^{n}$$

Where:

PPV_{equip} = the estimated PPV induced by the equipment at the monitoring location

PPV_{ref} = the PPV induced by the reference equipment at 25 ft (7.6 m)

D = the distance from the source to the receptor

n = the value related to the vibration attenuation rate through ground.

The vibration attenuation model for an impact pile driver is given by the following (CALTRANS 2013):

$$\mathbf{PPV}_{PD} = PPV_{ref}\left(\frac{25}{D}\right)^{n}\left(\frac{E_{equip}}{E_{ref}}\right)^{0.5}$$

Where,

PPV_{PD}	= the Peak Particle Velocity produced by a pile driver (in/s)
PPV_{ref}	= 0.650 in/sec for a reference pile driver at 25 ft from the receiver
D	= the radial distance between the pile driver and the monitoring point (ft)
n	= the value related to the attenuation rate through ground
E_{ref}	= 36,000 ft-lbs. (rated energy of reference impulsive pile driver)
E_{equip}	= 44,254 ft-lbs rated energy of the assumed impulsive pile driver

The value of "n" based on site-specific soil conditions can be used for an estimation of vibration amplitude was presented by CALTRAN (2013) and is shown in Table 2.

Table 2: Suggested "n" Values Based on Soil Class

Soil Class	Description of Soil Material	Suggested Value of "n"
I	Weak or soft soils: loose soils, dry or partially saturated peat and muck, mud, loose beach sand, and dune sand, recently plowed ground, soft spongy forest or jungle floor, organic soils, topsoil. (shovel penetrates easily)	1.4
II	Competent soils: most sands, sandy clays, silty clays, gravel, silts, weathered rock. (can dig with shovel)	1.3
III	Hard soils: dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock. (cannot dig with shovel, need pick to break up)	1.1
IV	Hard, competent rock: bedrock, freshly exposed hard rock. (difficult to break with hammer)	1.0

Note: Source – CALTRANS (2013)

Based on the information for this site and Golder's Draft Geotechnical/Pavement Investigation, Soil Class II has been assumed and a value of 1.3 was used in the assessment. Based on the values provided by CALTRANS (2013) and using the higher tonnage value the following values for PPV_{ref} were used in our assessment:

Table 3: Suggested PPVref for Various Equipment Types

Equipment	PPVref (in/sec)
Excavators (50 Tonnes)	0.089
Vibratory Rollers (15.5 Tonnes)	0.210
Crawler Dozer (13 Tonnes)	0.089
Trucks	0.079
Asphalt Pavers (21.5 Tonnes)	0.089
Asphalt Material Transfer Vehicle (Shuttlebuggy)	0.089
Asphalt Pavement Profiler (Milling Machine) (51 Tonnes)	0.089
Caisson Drill	0.089
Vibratory and Impact Pile Drivers	0.650

The predictive vibration models developed for the proposed construction operations, which have been converted to mm/s, and the ground vibrations limits for the proposed vibration limits are shown graphically in Figure 3.

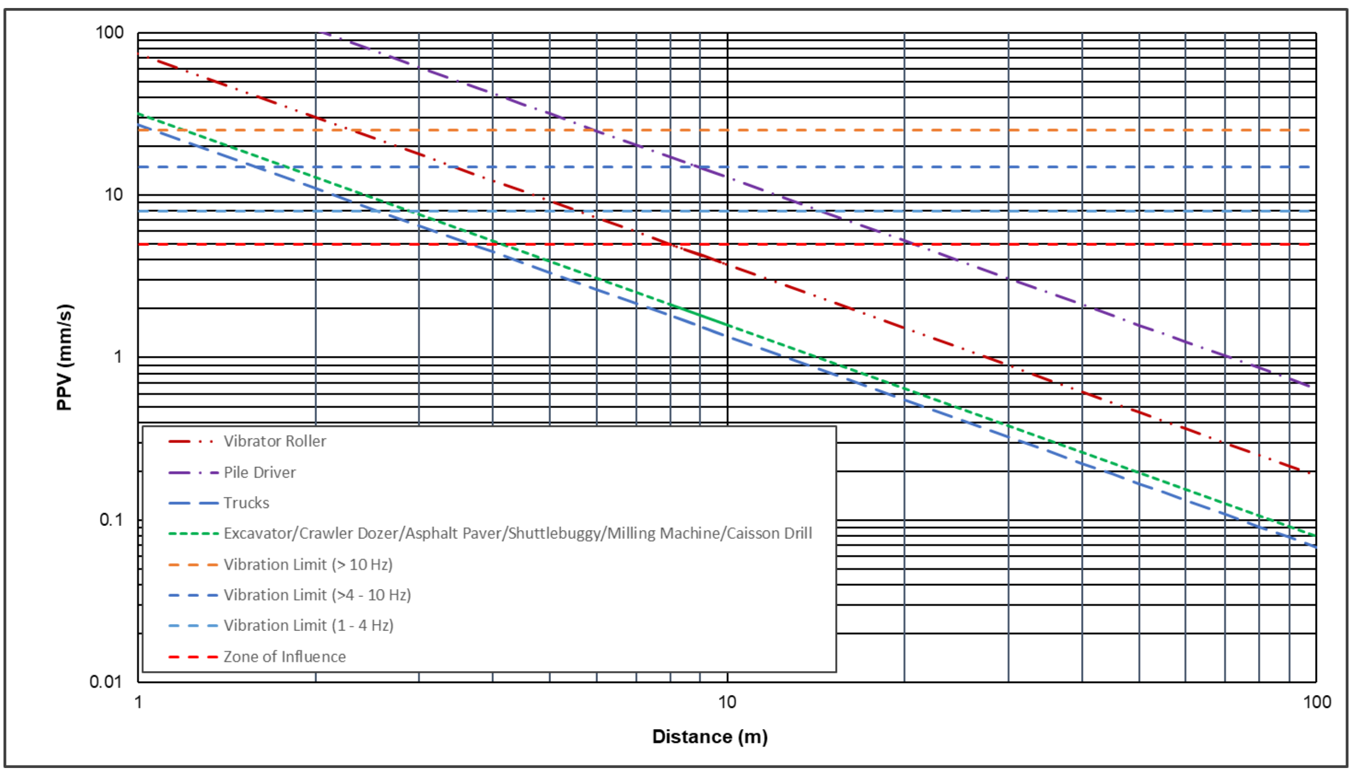


Figure 3: Ground Vibration Attenuation Model for the Proposed Construction Operations

3.2 Estimated Vibrations

3.2.1 Equipment Induced Vibration Estimates on Structures

The crane operated pile driver should produce the highest vibration levels during the proposed construction operation for either the overpass or underpass scenario. Additionally, the vibratory compactor/roller (in vibratory mode) should produce the highest vibration levels outside of the boundary of the impact and vibratory pile drivers during the proposed construction operation on the road segments being reconstructed but induces far lower vibration levels compared to the pile drivers. Thus, the impact and vibratory pile driver, and the vibratory roller will be used to conservatively estimate the potential vibrations induced during the proposed project. The estimated separation distances between the proposed road construction equipment and the identified receptors for the various thresholds described above will be as follows:

Impulsive Pile Driver:

- Zone of Influence (5 mm/s) for a separation distances of 20.7 m (pile driver);
- Assumed Vibration Limit:
  - < 4Hz (8 mm/s) for a separation distance of 14.4 m (pile driver);
  - 4 – 10 Hz (15 mm/s) for a separation distance of 8.9 m (pile driver); and
  - > 10Hz (25 mm/s) for a separation distance of 6.0 m (pile driver).

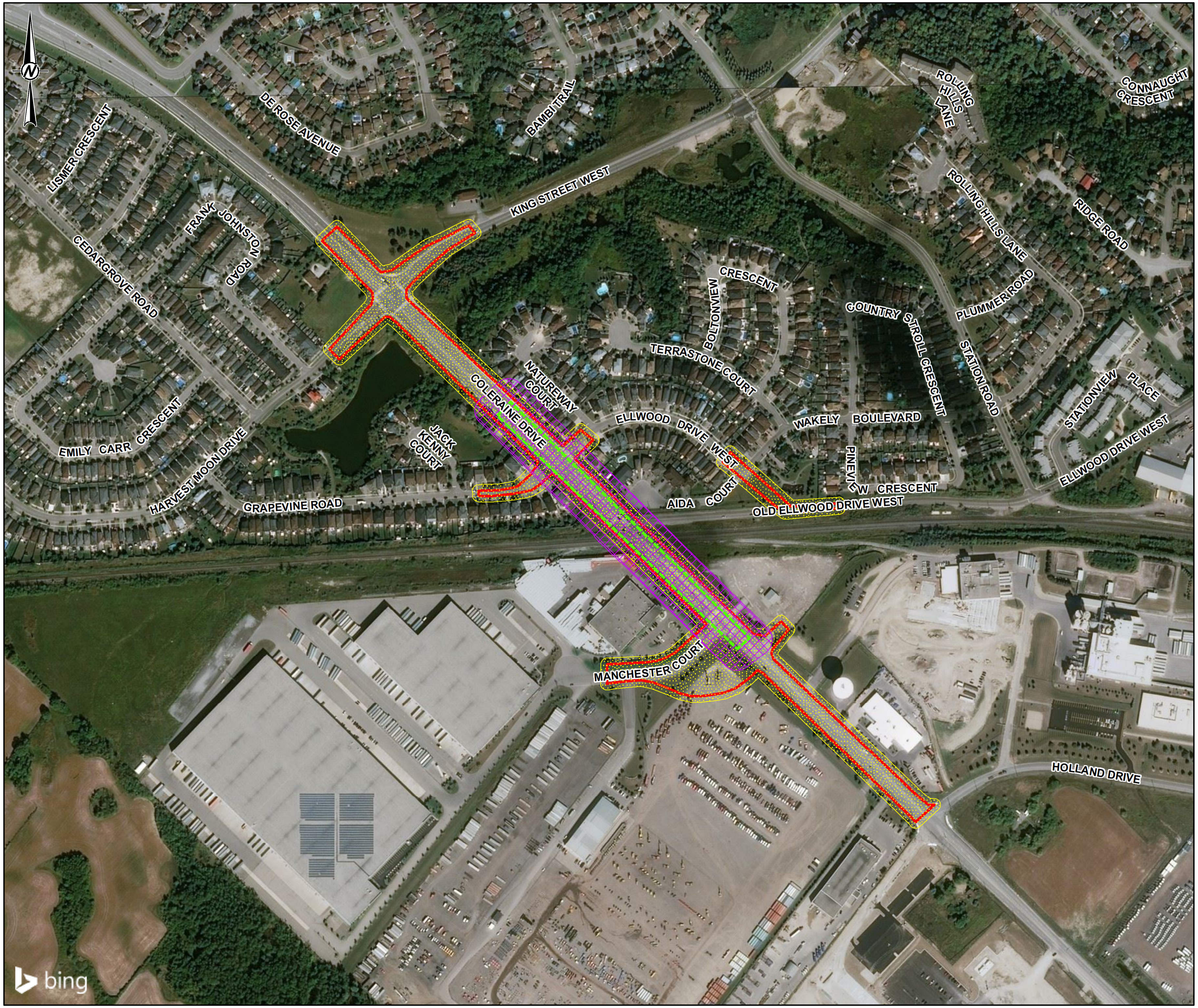
Vibratory Pile Driver:

- Zone of Influence (5 mm/s) for a separation distances of 19.1 m (vibratory pile driver);
- Vibration Control By-Law:
  - < 4Hz (8 mm/s) for a separation distance of 13.3 m (vibratory pile driver);
  - 4 – 10 Hz (15 mm/s) for a separation distance of 8.2 m (vibratory pile driver); and
  - > 10Hz (25 mm/s) for a separation distance of 5.5 m (vibratory pile driver).

Vibratory Roller:

- Zone of Influence (5 mm/s) for a separation distances of 8.0 m (vibratory roller);
- Vibration Control By-Law:
  - < 4Hz (8 mm/s) for a separation distance of 5.6 m (vibratory roller);
  - 4 – 10 Hz (15 mm/s) for a separation distance of 3.4 m (vibratory roller); and
  - > 10Hz (25 mm/s) for a separation distance of 2.3 m (vibratory roller).

A contour line showing the vibration ZOI from the two proposed construction scenario, overpass and underpass, operations are shown in Figure 4A and Figure 4B, respectively. The yellow hatch indicates the ZOI for the vibratory compactor/roller, the purple hatch indicates the ZOI for the pile driver and the green boundary is the assumed boundary the pile driver would work within. Should a specific work boundary for the pile driver be provide by CIMA+ and/or the Region both the Figures and attenuation model can be revised.



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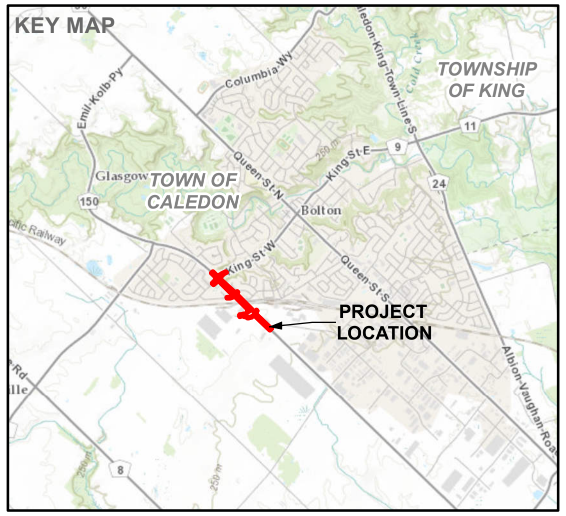
- Study Area/Extent of Vibratory Roller
- Extent of Pile Drivers
- Zone of Influence - Pile Drivers
- Zone of Influence - Vibratory Roller



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3. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83 COORDINATE SYSTEM:UTM ZONE 17N

CLIENT
CIMA+ AND REGIONAL MUNICIPALITY OF PEEL.

PROJECT
ZOI, PROPOSED COLERAINE DRIVE GRADE SEPARATION SOUTH OF OLD ELLWOOD DRIVE, TOWN OF CALEDON

TITLE
ZONE OF INFLUENCE, OVERPASS SCENARIO

CONSULTANT
GOLDER

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REVIEWED	JS
APPROVED	-

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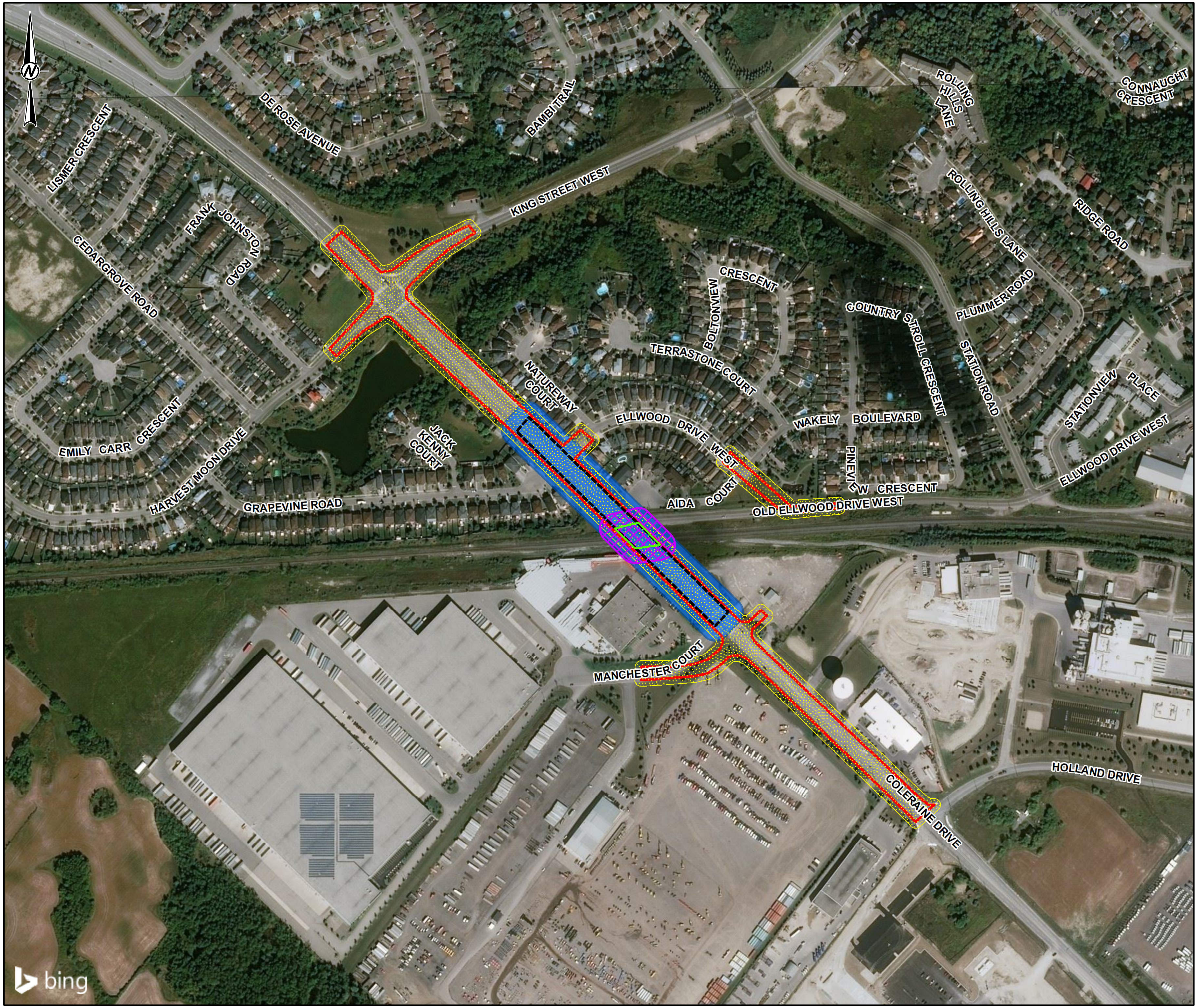
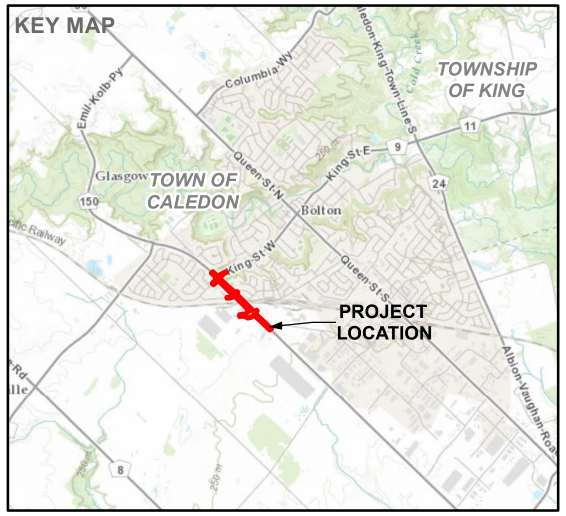


LEGEND

- Study Area/Extent of Vibratory Roller
- Extent of Impact Pile Driver
- Extent of Vibratory Pile Driver
- Zone of Influence - Pile Driver
- Zone of Influence - Vibratory Pile Driver

KEY MAP



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3. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83 COORDINATE SYSTEM:UTM ZONE 17N

CLIENT
CIMA+ AND REGIONAL MUNICIPALITY OF PEEL

PROJECT
ZOI, PROPOSED COLERAINE DRIVE GRADE SEPARATION SOUTH OF OLD ELLWOOD DRIVE, TOWN OF CALEDON

TITLE
ZONE OF INFLUENCE, UNDERPASS SCENARIO

CONSULTANT
GOLDER

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3.2.2 Overpass Construction Scenario

The overpass construction scenarios estimated separation distances and calculated PPV for the worst-case equipment for each of the representative receptors for the proposed construction are summarized in Table 4.

Table 4: Estimated Ground Vibration Levels from the Overpass Construction Scenario Equipment at the Vibration Receptors

Receptor ID	Highest Vibration Source Equipment	Distance (m)	PPV (mm/s)
R1	Impact Pile Driver	13	9.14
R2	Impact Pile Driver	63	1.17
R3	Impact Pile Driver	15	7.59
R4	Vibrator Roller	15	2.21
R5	Vibrator Roller	15	2.21
R6	Vibrator Roller	14	2.42
R7	Vibrator Roller	9	4.30
R8	Vibrator Roller	12	2.96
R9	Vibrator Roller	10	3.75
R10	Vibrator Roller	15	2.21
R11	Vibrator Roller	26	1.08
R12	Vibrator Roller	52	0.44
R13	Impact Pile Driver	13	9.14
R14	Vibrator Roller	9	4.30
R15	Vibrator Roller	10	3.75
R16	Vibrator Roller	10	3.75

The estimated vibrations at the nearest structures to the proposed renovation were marginally above the assumed vibration limit of 8 mm/s (for vibration frequencies less than 4 Hz). In our experience, the dominant frequencies for vibratory rollers and impact pile drivers at short distances are at frequencies above 4 Hz. For dominant frequencies above 4 Hz, the estimated vibration levels were all below the assumed guideline limit. However, this would need to be confirmed during site-specific vibration monitoring. The ZOI for the proposed construction operations extends beyond the legal boundaries of the construction site for much of the project. In a small number of locations, the ZOI extends to the nearest sensitive receptor. Where the road construction operations for the impact pile driver or vibratory roller occur within about 80m or 70m, respectively, of an adjacent structure, the induced ground vibrations are likely to be perceived. If the vibratory pile driver would be used the induced ground vibrations are likely to be perceived within 160m.

3.2.3 Underpass Construction Scenario

The underpass construction scenarios estimated separation distances and calculated PPV for the worst-case equipment for each of the representative receptors for the proposed construction are summarized in Table 5.

Table 5: Estimated Ground Vibration Levels from the Underpass Construction Scenario Equipment at the Vibration Receptors

Receptor ID	Highest Vibration Source Equipment	Distance (m)	PPV (mm/s)
R1	Vibratory Pile Driver	13	8.24
R2	Impact Pile Driver	63	1.17
R3	Vibratory Pile Driver	15	6.84
R4	Vibratory Pile Driver	15	6.84
R5	Vibratory Pile Driver	15	6.84
R6	Vibrator Roller	14	2.42
R7	Vibrator Roller	9	4.30
R8	Vibrator Roller	12	2.96
R9	Vibrator Roller	10	3.75
R10	Vibrator Roller	15	2.21
R11	Vibrator Roller	26	1.08
R12	Vibrator Roller	52	0.44
R13	Vibratory Pile Driver	13	8.24
R14	Vibratory Pile Driver	15	6.84
R15	Vibrator Roller	10	3.75
R16	Vibrator Roller	10	3.75

The estimated vibrations at the nearest structures to the proposed renovation were marginally above the assumed vibration limit of 8 mm/s (for vibration frequencies less than 4 Hz). In our experience, the dominant frequencies for vibratory rollers, vibratory pile drivers and impulsive pile drivers at short distances are at frequencies above 4 Hz. For dominant frequencies above 4 Hz, the estimated vibration levels were all below the assumed guideline limit. However, this would need to be confirmed during site-specific vibration monitoring. The ZOI for the proposed construction operations extends beyond the legal boundaries of the construction site for much of the project. In a small number of locations, the ZOI extends to the nearest sensitive receptor. Where the road construction operations for the impact pile driver, vibratory pile driver or vibratory roller occur within about 80 m, 160 m or 70 m, respectively, of an adjacent structure, the induced ground vibrations are likely to be perceived.

4.0 DISCUSSION AND CONCLUSIONS

As shown in Table 4, Table 5, Figure 4A and Figure 4B, the ZOI extends beyond the legal boundaries of the construction site for much of the project. The proposed overpass and underpass construction-induced vibration has two receptors (R1 and R13) which are marginally above the proposed vibration limit 8 mm/s (for vibration frequencies less than 4 Hz). In our experience, the dominant frequencies for vibratory rollers, vibratory pile drivers and impact pile drivers at short distances are at frequencies above 4 Hz. The maximum frequency-based vibration limits for frequencies of >4-10 and >10 Hz are 15 and 25 mm/s, respectively. Thus, the anticipated vibrations will be below guideline limits. However, this would need to be confirmed during site-specific vibration monitoring. Where road construction operations (using pile drivers (impact and/or vibratory) and vibratory rollers) occur within 70-160 m of residences, the induced ground vibrations are likely to be perceived and could be an annoyance.

Although vibration monitoring is typically only required within the ZOI, continuous vibration monitoring tends to provide data which allows for ongoing feedback to the Project Team regarding the vibrations produced and to expedite complaint resolution.

It is recommended the CIMA+ and the Region will carry out the following:

- Preconstruction condition surveys should be carried out on adjacent residences within the ZOIs. These properties are detailed in Figure 4A and Figure 4B, which are predominantly the first row of homes either backing or siding Coleraine Drive; and
- Vibration monitoring for the duration of the construction activities.

The estimated number of preconstruction survey for the overpass scenario would be 15 homes and for the underpass scenario it would be 11 homes.

5.0 CLOSURE

We trust that the information presented in this report meets your current requirements. Should you have any questions or concerns, please do not hesitate to contact the undersigned.

Signature Page

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APPENDIX A

Vibration Terminology

VIBRATION TERMINOLOGY

The following terms have been defined in the Construction Vibrations By-Law 514-2008 and are applicable within this document:

Construction Equipment — Any equipment or device designed for use in construction, or material handling including, but not limited to, air compressors, pile drivers, pneumatic or hydraulic tools, bulldozers or trucks, tractors, excavators, trenchers, cranes, derricks, loaders, scrapers, pavers, generators, ditchers, compactors and rollers, pumps, concrete mixers, graders, or other material handling equipment.

Construction Vibration — Vibration occurring as a result of the operation of construction equipment during construction.

Frequency of Vibration — Rate of oscillation that occurs in one second, measured in hertz where 1 hertz equals 1 cycle per second.

Ground Vibrations Intensity — The intensity of ground vibration, an elastic effect measured in units of peak particle velocity (PPV), is defined as the speed of excitation of particles within the ground resulting from vibratory motion. Vibration energy from construction operations can emanate from a variety of sources including:

- Impulsive (breakers, dynamic compaction, impact pile driving);
- Vibrating (vibratory compaction roller, vibratory pile driving);
- Rotating (trencher, drilling/auguring equipment); and
- Rolling (heavy vehicles) type equipment.

The intensity of the vibration produced by each source depends on the input energy, its frequency, the transmission medium, and distance of travel.

Peak Particle Velocity (PPV) — Maximum rate of change with respect to time of the particle displacement, measured on the ground, and velocity amplitudes are given in units of millimeters per second from zero to peak amplitude.

Vibration Control Form — Form prescribed by the Chief Building Official to provide information regarding construction vibration to accompany an application for a permit.

Zone of Influence — Area of land within or adjacent to a construction site, including any buildings or structures, that potentially may be impacted by vibrations emanating from a construction activity where the peak particle velocity measured at the point of reception is equal to or greater than 5 mm/sec at any frequency or such greater area where specific site conditions are identified by the professional engineer in a contemplated study.

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